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BROADCASTING BY MEANS OF SATELLITES

by N. I. Chistyakov

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BROADCASTING BY MEANS OF SATELLITES

N. I. Chistyakov[1]

ABSTRACT: The principles involved in the construction of a satellite broadcasting network are discussed; the differences and advantages as well as shortcomings of elliptical and circular orbits, both equatorial and inclined to the plane of the equator, are outlined. The differences between passive and active communications satellites are pointed out and factors which complicate the use of satellites for international radio and television broadcasting are discussed (differences in language, time, broadcasting standards, and population distribution).

INTRODUCTION

Radio and television make the latest achievements of culture generally available, allow rapid and widespread propagation of information regarding life and events over the entire world, and communicate advanced ideas and knowledge. The prediction made by V. I. Lenin, who called radio a newspaper "without paper and 'without distances'--a great thing, an enormously important affair", has come true. The Twentieth Century is rich in technical achievements; they include atomic electric power stations, electronic computer centers, supersonic aircraft and the flights of space ships to other planets. It is quite possible, however, that a future historian of the technology of our era will place the development of television and radio broadcasting in first place as far as direct social significance is concerned. /3*

One of the most interesting chapters in the history of radio and television opened when space exploration began and communication satellites were built which allowed any radio signals (for example, such complex ones as the voices of thousands of telephone subscribers or television signals simultaneously) to be transmitted over thousands of kilometers through deserts and over

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*Numbers in the margin indicate pagination in the foreign text.

oceans. This is especially important in the case of television, since there are other effective means for telephone communication which are undergoing rapid development (underground and underwater cables, radio relay lines, etc.)

A satellite in a communications and broadcasting system serves as a means of elevating a radio transmitter above the earth to a great height in order to increase the range of transmission. This necessity arises from the fact that meter and decimeter waves are used for television transmission. Unlike short, medium and longwaves which are used for radio communication and broadcasting and are not suitable for television, the radio waves in the television frequencies can propagate within limits which are scarcely greater than the line-of-sight distance of the transmitting antenna from the receiving point; they cannot go around the curvature of the earth and therefore undergo rapid deterioration with increasing distance beyond the line of the horizon, so that reception soon becomes impossible. For this reason the effective radius of television transmitters is usually no more than 60 to 80 km.

In order to increase the effective radius of the Moscow television center /4
to 120 km, a tower more than half a km high was built, on which the television transmitting antennas are mounted. It is possible that in the near future similar towers will be used in other cities, but their cost is still very high and the possibility of a considerable increase in their altitude is unlikely.

Another solution to the problem lies in locating the television transmitter on an aircraft (or a balloon), flying at an altitude of several km. This solution was proposed by one of the pioneers in television, Professor P. V. Shmakov. Tests were conducted in the USSR in 1957 during the World Festival of Youth and Students in Moscow and gave positive results. However, aircraft systems cannot insure television reception over the territory of a large country or several countries. A satellite, however, makes it possible to raise the transmitter to a height of thousands and tens of thousands of km. It is clear from Figure 1, which is a schematic representation of the position of a satellite at different heights (positions A, B, C, D), that the higher the satellite is above the earth, the greater the area within which the signals transmitted by it can be received.

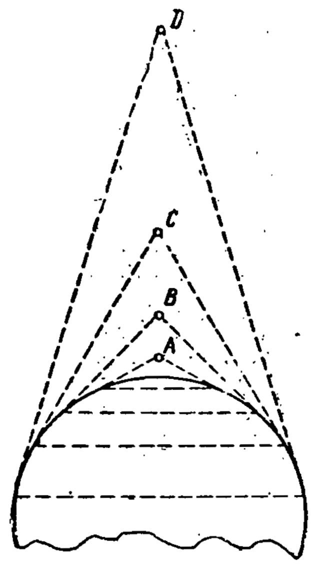

Figure 1.

When the Soviet nation was marking the 50th Anniversary of the Great October Socialist Revolution, twenty television transmitters linked with receiving stations in the "Orbita" system and located many thousands of kilometers distant from the capital of the country, were able to receive the program from the central television studies through "Molniya-1" satellites. About twenty million inhabitants of rural areas and remote districts in our land were able to see television broadcasts from Moscow.

The idea of using satellites to transmit radio programs was originated about 25 years ago. Its author is an English writer well-known in our country, the scientist Arthur /5
Clarke. He proposed that a radio transmitter be placed in a stationary satellite and used to transmit radio and television programs to earth. Three such satellites, each located one-third of the orbit away from the next (Figure 2), would make it possible to transmit radio or television programs to the entire earth, with the exception of the areas near the poles. Solar batteries were suggested as the source of electrical energy for the transmitters.

Even K. E. Tsiolkovskiy showed in his works that if a satellite is located in a circular orbit at a height of approximately thirty-six thousand kilometers above the surface of the earth and if its orbit lies in the plane of the equator and its direction of motion coincides with the direction of rotation of the earth on its axis, this satellite and the earth will rotate synchronously and the satellite will remain above the same area of the earth all the time, i.e., it will appear fixed as viewed from the earth. A satellite of this kind is called "stationary."

There are two different kinds of broadcasting, radio and television. From the standpoint of utilization of satellites, television transmission is of the

greatest interest at the present time, since it is a source of much richer /6
and more graphic information for the subscriber.

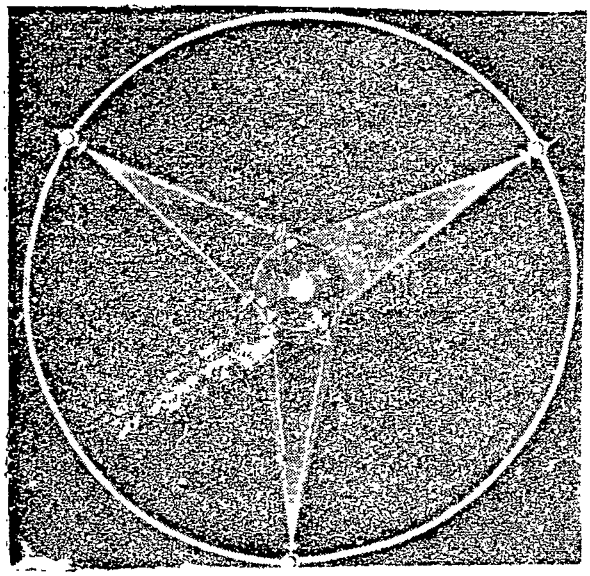

Figure 2.

Transmission of radio programs does not necessarily require the use of satellites. Broadcasting on long and medium waves covers immense distances, while short waves are able to transmit radio programs practically without any limitation on distance. In addition, there are simple and effective ways of storing radio programs (transcription disks and magnetic tape), Air transport makes it possible to bring radio programs to all corners of the earth. The recording and broadcasting of television programs is still subject to considerable difficulties and the costs are greater. Satellites, however, open up the possibility of transmitting television programs over any distance to territories of any size.

The general features of broadcasting systems employing satellites are the following:

Programs from ground stations are transmitted to the satellite; the programs are relayed back to earth by the radio equipment in the satellite and can be picked up anywhere within the territory covered by the satellite;

Programs from the satellite can be picked up by residents of the territories served by it.

Transmission of information relayed through a satellite is called "satellite communication." This system of radio broadcasting can therefore be called "satellite broadcasting."

There are several systems of satellite broadcasting. They differ in the type of equipment used on the ground to receive the transmissions from the satellite and pass them on to the population and also in the type of satellites used.

Passive and Active Communication Satellites

In principle, radio communications and broadcasting can be accomplished either through the natural satellite of the earth, the moon, or through an artificial satellite. In view of the considerable distance to the moon and other reasons, broadcasting via the moon is still impractical, so that our practical interest will be limited to those systems using artificial satellites.

There are two possible ways of transmitting signals via a satellite to the earth:

(1) using the satellite as a mirror reflecting radio waves to the earth which it has received from a ground transmitter. A communications satellite of this kind is called "passive";

(2) use of the satellite as a relay station. Both rèceiving and transmitting equipment is installed in the satellite. The signal from the ground transmitting station is received by the satellite receiver, amplified and radiated to the earth through an antenna. A communications satellite of this type is called "active." /7

A striking feature of the passive satellite is the fact that it requires no electronic apparatus of any kind. It can therefore be of simple construction and a high degree of reliability. Since this satellite only reflects all the waves which reach it from the earth, all operations involving regulation and changing of wavelength, power and other characteristics of the radio signal are carried out on earth. The satellites of this type which have actually been made have taken the form of a simple large sphere made of thin metallized plastic film.

The signals reflected by the satellite reach only those point on the earth surface from which it can be seen above the line of the horizon. As we have already mentioned, the territory served will increase in size as the height of the satellite increases. This height can reach hundreds and thousands of kilometers so that a very small quantity of energy transmitted from the ground reaches the satellite and is reflected from it to the earth (Figure 3). For example, if the distance from the transmitter to the satellite is ten thousand kilometers and the diameter of the satellite is 100 m, the solid angle relative to the transmitter for this diameter at the given distance will only be approximately 2 seconds of angle.

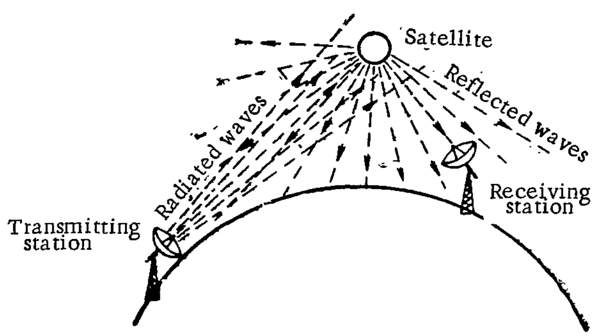

Figure 3.

A modern antenna used to transmit signals to a communications satellite from a ground station is a complex engineering structure of large size which is the most expensive part of the station. However, it makes it possible to concentrate the radiation in a solid angle of only 5 to 10 minutes of angle. The surface of the satellite will then amount to only 0.001 to 0.003% of the cross-sectional area of the radio wave. In other words, only one-third of the hundreds and thousands of watts of energy radiated by the transmitter will reach the surface of the satellite, and of this negligible quantity of energy only a very small part will be reflected from the spherical surface of the satellite to the earth. In order to concentrate the reflected energy in the direction of the earth, it would be necessary to give the satellite the shape of a concave mirror and orient it precisely in space. This would lead to a considerable complication of the satellite's structure and the installation aboard it of equipment for remote control and stabilization, so that it would lose its advantages of simplicity of construction and high reliability. /8

Even if all this energy were reflected in the direction of the earth without losses and fell directly on the territory to be served, the flow of energy from the earth to the satellite would have to be 30 to 100 thousand times more powerful than the required flow of energy from the satellite to the earth. Consequently, it would be necessary to add a still greater concentration of radiation from the ground transmitter and to increase its power; this would mean that the antenna would have to be of enormous dimensions and be aimed at the satellite with a very high degree of accuracy, and the power of the transmitter would be thousands of times greater than that of ordinary radio broadcasting stations. For this reason, passive satellites have turned out to be of little value and are practically not used at all in modern satellite communication systems.

It is more advantageous to equip the satellite with radio equipment which will provide a sufficient increase in the relayed signal. The energy to power the apparatus aboard the satellite can be obtained from solar batteries.

In the following sections of this booklet, we shall discuss only systems with active satellites.

Types of Television Broadcasting Systems Using Satellites

The radio transmitters mounted aboard "Molniya-1" communication satellites have a power of 40 watts, with a distance of approximately 40,000 km between the satellites and the receiving stations. The powers of terrestrial television transmitters are measured in kilowatts and tens of kilowatts, with an /9 effective radius on the order of 100 km. It is obvious from this comparison that the signal received on the earth from the communications satellite transmitter is many times weaker than an ordinary television signal received by a television set, so that it can be picked up only by special stations which are equipped with complex instruments. The possibility of simplifying the receiving apparatus depends on further increases in the power of the transmitter aboard the satellite.

In order for television viewers to receive a program transmitted via satellite, the signals received by the ground station must travel through radio relay or cable links to the radio transmitters of the existing television broadcasting network, to be retransmitted and picked up by means of conventional television receivers owned by the population. No changes are made in the ground network for television broadcasting within the affected area; satellite radio communication merely plays the role of an additional means of transmitting the program in this network. A system of this kind is used to replace relay stations between remote areas of the country or between different countries. Figure 4 shows a transmission using a system of the type described above, in one direction (from point A to point B). Two way communication is also possible. In this case, both stations act as receivers and transmitters. An example of this type of use of a satellite is the exchange of television programs between Moscow and Vladivostok, and also between Moscow and Paris via the "Molniya-1" communication satellites.

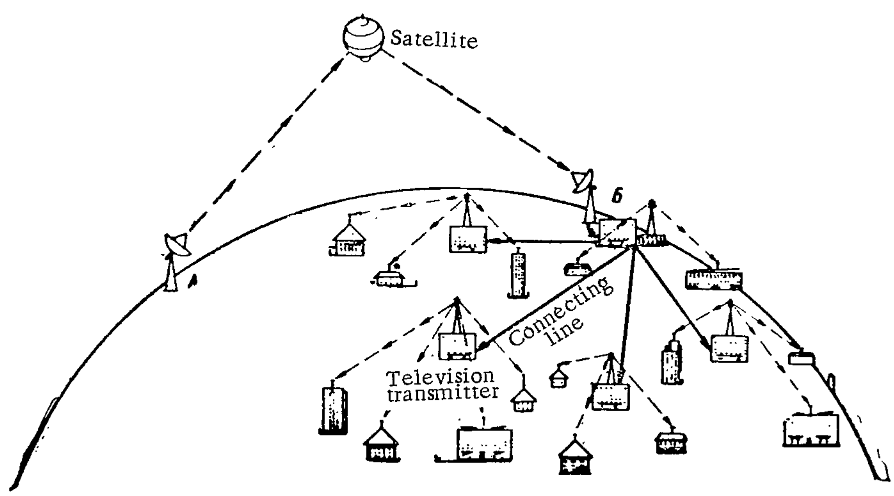

Figure 4.

Figure 5 shows a diagram in which satellites are used as the principal means of relaying television programs over considerable distances. The signals from the satellite are picked up by ground stations at several points and relayed to television transmitters at local television centers, which broadcast them to the population of the surrounding areas. In this case, the satellite /10 "distributes" the television programs to the stations belonging to this system and is therefore called a "distributing" radio-broadcasting satellite. Thus, the Soviet communication satellite system "Orbita" was built to make it possible to send programs from the central television studio to 25 million citizens living in regions of the country far from Moscow.

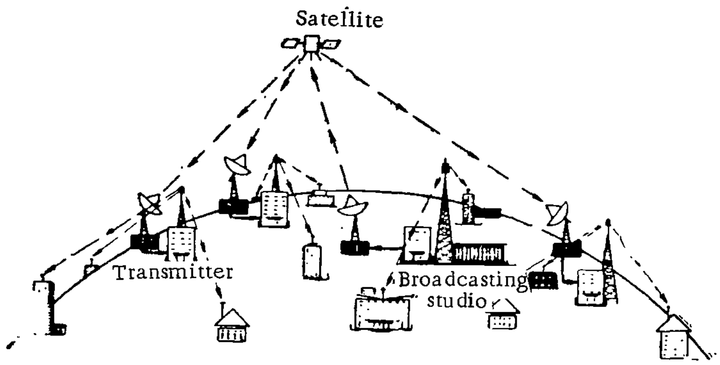

Figure 5.

If the power of the transmitter aboard the satellite is increased, the signal level also will increase at the receivers on the ground. This leads to a simplification of the receiving and relaying apparatus and also makes it possible to pick up signals from a satellite directly on the television receivers located in the home (Figure 6). Radio broadcasting systems of this kind which use satellites have been called a "system of direct broadcasting."

There are two possible versions of such a system[1].

1. A system which assumes the use of conventional receivers and antennas located in the home without any conversion or attachments. We can call a system of this type "generally available." /11

[1]The names of the types of systems of direct broadcasting are used by the author to simplify the exposition of his material and are not official terms (Editor).

2. A system which requires that the subscribers have receivers and antennas specially intended for receiving programs transmitted via satellite. A system of this kind will be called "special."

3. A system using the existing ordinary receivers but requiring addition tional attachments to these receivers in order for satellite signals to be received, in the form of additional antennas and some kind of attachment. A system of this kind for direct broadcasting via satellites will be called "adaptable."

4. A system using the conventional receivers without any kind of individual attachments for receiving programs from the satellite but requiring joint facilities to serve a group of subscribers. Since this kind of system is intended for more or less large groups rather than isolated independent subscribers, we will call it a "collective" system.

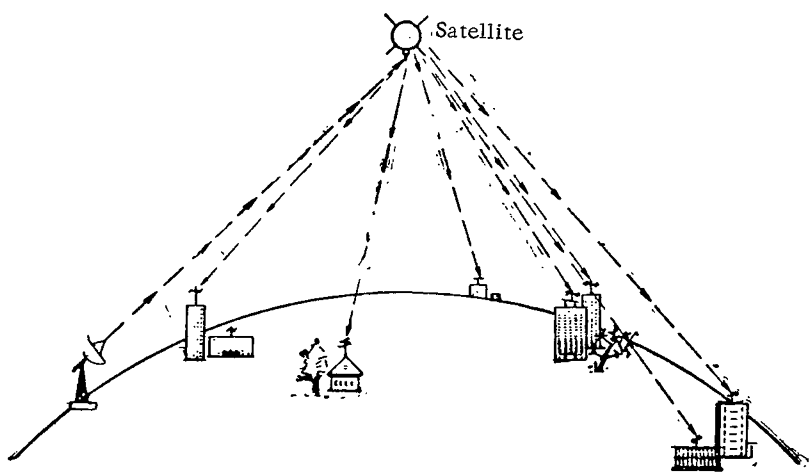

Figure 6.

In the final sections of this booklet we will give a comparative estimate of these types of systems of satellite broadcasting. We will limit ourselves here to a brief general description of the characteristics of the systems of direct broadcasting without taking up the question of reality or the difficulties in their practical achievement.

The collective system is not separated by a definite boundary from the distributing system described above; in this case, the communication satellite transmitter must have sufficient energy that the collective receiving equipment can be made simply, cheaply and therefore relatively large. Cables can be used to transmit the signals received from the antenna to the individual receivers as is done in high rise buildings in cities which use master antennas for television reception. /12

The generally available system is the most complete realization of the idea of direct broadcasting via satellite. A system of this kind could go into action immediately following launching of the satellite. It will be shown later on that there are serious reasons for doubting the possibility of constructing a system of this kind in the near future. One reason for this is the need for a very large satellite with a powerful transmitter, which entails overly great expenditure in its launching.

The special system, suitable only for reception of programs via satellite, is unsuitable for use in areas where there is already a network of ground television stations and where the population has conventional receivers. Experience has shown that if the population already has the possibility for regularly receiving programs via an existing broadcasting network, it will be unwilling to agree to significant additional expenditures. An example of this is the fact that even color television is spreading very slowly regardless of the new qualitative effect which is obtained. Its introduction has been made possible through the selection of a compatible system, i.e., one which has made it possible to watch color broadcast using conventional "black and white" receivers (of course, the image received on the latter is not in color).

The adaptable system is more realistic, but the widespread development of such systems in areas where there is already a ground network of television broadcasting will also encounter resistance. Adapters for conventional receivers and special antennas which are required for receiving programs from the satellites will hardly gain mass acceptance. This is indicated, for example, by the experience in using different types of devices for receiving radio programs transmitted on meter waves with frequency modulation and stereophonic programs on old receivers intended for receiving amplitude modulated signals. These devices have found very small demand and use. The solution to the problem has been the manufacture of large receivers capable of receiving radio transmissions of both kinds.

It is obvious that of the systems of direct television broadcasting by means of satellite which we have discussed above, the most realistic in the near future is the distributive (particularly the "Orbita" type) and the collective systems. /13

Orbits of Satellites Used for Radio Communication and Broadcasting

The orbits of satellites are characterized by the angle of inclination of the plane of the orbit to the plane of the equator, as well as the height and shape of the orbit.

As far as the angle of inclination is concerned, there are equatorial, polar and inclined orbits. In the first case, the plane of the orbit coincides with the plane of the equator; in the second case it coincides with the plane of the meridian and the angle of inclination is equal to 90°; the orbit of the satellite passes over the North and South Poles. In the third case, the angle of inclination of the plane of the orbit has a value between 0 and 90°.

There are both circular and elliptical orbits. In the first case, the shape of the orbit is close to a circle, i.e., the height of the satellite above the surface of the earth remains practically the same and the center of the orbit coincides with the center of the earth. In the second case the height of the satellite changes within relatively wide limits from a minimum value at perigee to a maximum at apogee. In accordance with Kepler's first law, one of the foci of an elliptical orbit coincides with the center of mass of the earth.

The motion of the satellite in its orbit follows Kepler's second law, according to which the radius-vector (in this case a straight line joining the satellite to the center of the earth) covers equal areas in equal intervals of time. According to this law the same period of time is required for the satellite to cover the portion of the orbit marked AB as is required to cover portion CD, so that the area of sectors AOB and COD (Figure 7) are equal. From this it follows that the speed of the satellite along its orbit is maximum at perigee and minimum at apogee. Consequently, in the case of a considerably elongated elliptical orbit (with a very high apogee) the satellite travels relatively slowly through the area of the apogee and rapidly through the area of the perigee.

The period of rotation of the satellite in hours can be determined by the /14
formula

$$T = 0{,}087 \sqrt{a^3}$$

where a is the major semiaxis of the elliptical orbit (Figure 7) or the radius of a circular orbit in thousands of kilometers.

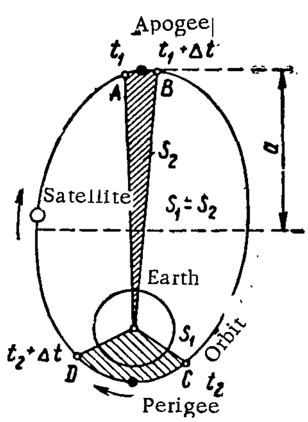

Figure 7

From this it follows in particular that when the radius of the orbit is approximately 42,000 km, i.e., when the satellite is approximately 36,000 km above the surface of the earth, its period of rotation is 24 hours. A satellite with such a period n a circular equatorial orbit and moving in the same direction as the direction of rotation of the earth on its axis (Figure 8) will be fixed relative to the surface of the earth. This is the only case when the length of the period of transmission of a broadcast via satellite can be indefinitely long.

When the plane of the orbit of the satellite shows considerable deviation from the plane of the equator and when it has a different period of rotation, the position of the satellite relative to the surface of the earth changes. In this case the length of the period of communication or broadcasting via satellite is limited to the time of its passage over the territory to be served. For example, when the satellite is at a height on the order of 2 to 5 thousand kilometers, the maximum duration of communication is 0.5 to 1 hr. In addition, as we showed in Figure 1, decreasing height means decreasing size of the area reached by the signals radiated /15 by the satellite. All of this considerably reduces the effectiveness of a broadcast from a satellite which has a low orbit, since it presents no advantages.

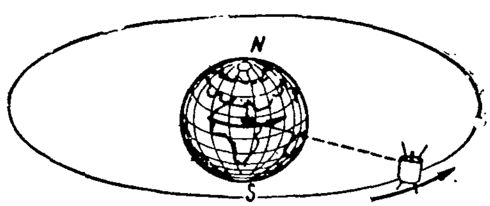

Figure 8.

With an elliptical orbit having a height at apogee of approximately 40 thousand kilometers and a height at perigee of approximately 0.5 thousand kilometers, the major semiaxis of the ellipse a = 27 thousand kilometers and the period of rotation T = 12 hours. A large part of this period corresponds to passage through apogee. Consequently, by broadcasting via satellite while the latter is located at areas of maximum height, it is possible not only to broadcast to a large territory but also to have a long period of continuous transmission (approximately 8 hours). The direction of movement of the satellite along its orbit must coincide with the direction of rotation of the earth; in this case, the rate of movement of the satellite relative to the earth in passing through apogee is somewhat less.

Therefore, from the standpoint of possible duration of continuous broadcasting, it is the orbit with the high apogee and stationary orbit which are of practical importance.

As we pointed out earlier, reception of signals from a satellite is possible over an area in which it is visible above the horizon. In practice, the region of reliable reception is somewhat smaller, since we must consider only the zone in which the satellite is observed above the horizon at an angle Θ_{min} = 5 to 7° (Figure 9). At smaller angles, the antenna of the ground re- /16 ceiver undergoes a rapid and considerable increase in the noise level of terrestrial origin.

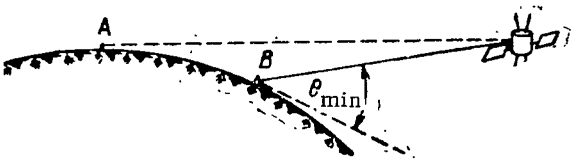

Figure 9.

In Figure 10, for a special case in which the satellite is located in a stationary orbit, we have shown the lines along which the satellite is visible from earth at various fixed angles relative to the horizon. In the area enclosed between 0° and 10°, reception is impeded by an increase in noise and is completely impossible beyond the 0°line. It is also apparent from this illustration that a stationary satellite makes it possible to cover completely such continents as Africa or South America, located on both sides of the equator and elongated in the meridianal direction. But one stationary satellite cannot simultaneously serve all of the European and Asiatic continents, which are located completely in the Northern Hemisphere and are elongated with latitude. For a simultaneous broadcast within the limits of the entire continent, two such satellites are required or a satellite of the "Molniya-1" type on an elliptical inclined orbit having its apogee above the region to be served (Figure 11). It is then visible within the limits of the shaded area for the entire period of its movement along the segment AB of its trajectory. According to Kepler's second law, the time required to traverse this segment consists of the portion of the period of rotation of the satellite which corresponds to the ratio of the area of sector AOB to the total area of the ellipse. In the example given, this ratio is approximately one-half, i.e., the satellite ensures long periods of communication and broadcasting for the entire shaded area. It should also be kept in mind, however, that in many cases simultaneous transmission of the same program to the western and eastern territories of a continent is not desirable due to the large difference in local time.

The following factors must be taken into account in selecting,comparing and choosing orbits:

Suitability of the orbit for the planned system; /17

Physical conditions to which the satellite is subjected in orbit;

Technical and economic factors involving the rocket system required to place satellites in comparable orbits.

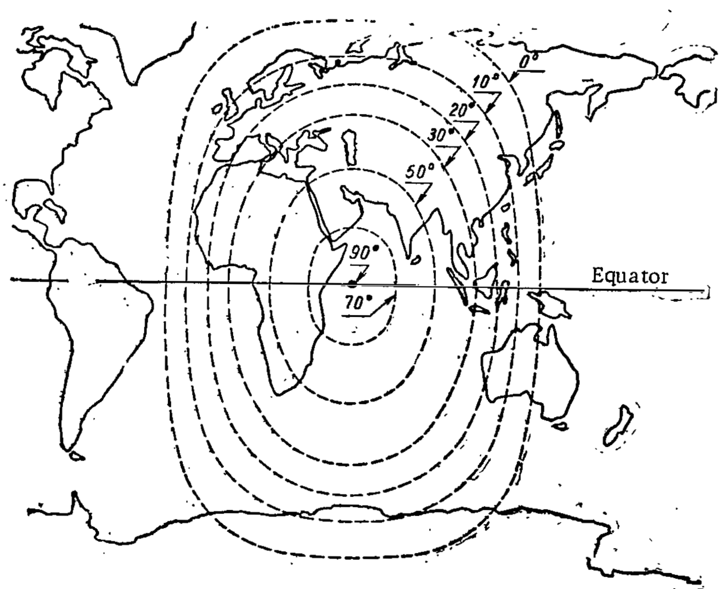

Figure 10.

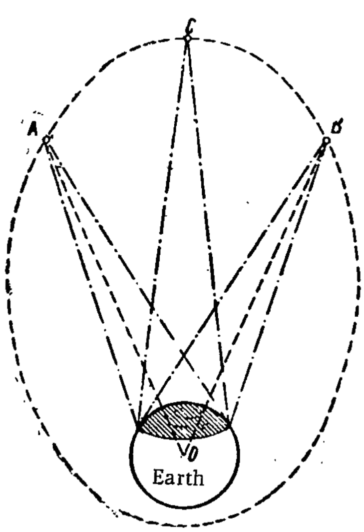

Figure 11.

The selection of an elliptical orbit is made in view of the fact that the earth is not a true sphere but flattened at the poles. This has an effect on the direction of the force of gravity acting on the satellite which differs somewhat from the direction at the center of the earth and changes as the satellite moves along its orbit. As a result, the major axis of the ellipse gradually changes its position relative to the axis of the earth, i.e., there is a change in the latitude of the apogee (this does not take place in the case of an elliptical equatorial orbit).

The inclined orbit most frequently used is tilted at an angle of 63° to the plane of the equator. In this case the latitude of the observer above which the apogee will fall remains fixed. An orbit of this kind is suitable for the Soviet Union and other countries which are located in the Northern Hemisphere, so that it is also employed for satellites of the "Molniya-1" type. In selecting the orbits of satellites intended for long term use, it is necessary to take into account the disturbing effect of outer space on conditions surrounding them. The radio equipment aboard the satellites can be damaged seriously by ionizing radiation in the form of a flux of protons with high energies. Bombardment of radio instruments by charged particles changes the physical properties of their elements and leads either to breakdown or to deterioration of the fundamental characteristics of the apparatus.

Studies conducted by Soviet and American scientists using spacecraft have shown that the earth is surrounded by equatorial belts of concentrated charged particles; there is an inner and an outer belt (shown schematically in Figure 12). The inner belt, which begins at a height of several hundred kilometers, has a concentration of high-energy particles (up to hundreds of millions of electron volts), mainly protons. The maximum concentration is found at a height of 8 to 9 thousand kilometers. Further out is the second belt, a zone which extends from 15-20 to 40-50 thousand kilometers, in which the concentration of particles (electrons) is very significant but their energy is comparatively small (tens and hundreds of electron volts). Beyond the limits of the outer belt, at a distance of 45 to 80 thousand kilometers, one more belt ("outermost") has been found, consisting of low-energy particles.

In order to protect the equipment aboard the satellite from radiation in the zone of maximum activity (at altitudes from approximately 1,800 to 9,000 kilometers), metal screens tens of centimeters thick would be required; this /18 is impractical due to the very high weight. This means that the orbits must be selected so that they pass through the less dangerous zones. The most reliable solution to the problem consists in using a stationary satellite located in a high circular orbit. The parameters of an elliptical orbit can also be chosen so that the internal radiation belts will be involved to a minimum degree, but it is much more difficult to do away completely with its harmful influence in this case.

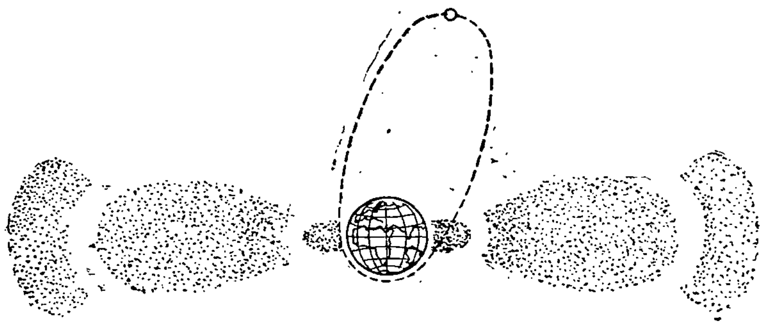

Figure 12.

Selection of Wavelength

Long range radio communication between points on the ground without a satellite is usually accomplished with shortwaves. At this wavelength, the waves from the transmitter do not pass through the atmosphere but are reflected from its ionized layers, located at heights of 100-300 km, and reach receivers thousands of kilometers away. However, a peculiar feature of satellite communication and broadcasting is that waves from a ground station to a satellite and from a satellite to the ground must move freely through the atmosphere. The range of wavelengths in which the transmitted radio signal pass through the atmosphere without excessive absorption and refraction is called the atmospheric "radio window." The longest waves in this region are 20-30 meters and the shortest are 1.5 to 3 cm. Longer waves are reflected from the ionosphere and do not pass through it from the earth to outer space or in the opposite direction, while the shorter ones are considerably absorbed by the atmosphere. Other radio windows exist in the range of waves much shorter than 1.5-3 cm.

In the range of the very longest waves in this region, a considerable influence on radio reception is exerted by extraneous radiation of cosmic /19 origin as well as thermal radiation which arises in the earth and in the atmosphere. These are referred to as noise and can disturb reception of weak radio signals. The shorter the wavelength, the less the effect of these noises; when waves 15-30 cm long are used for radio communication, their level decreases to the level of the natural noise of the radio receivers. If the wavelength is less than 4-5 cm, the absorption of radio waves in the atmosphere increases due to the presence of water vapor and droplets, smoke particles, dust and so on.

For the reasons given, it is most advantageous for satellite communication to use the range of radio waves from 4 to 15 cm corresponding to frequencies of (7.5 to 2) 10^9 Hz, or (7.5 to 2) GHz[1]. However, this range is also the most suitable one for radio relay communication. Therefore, one of the most important problems in designing radio relay and satellite systems for communication is the joint use of common waves.

In order to avoid mutual interference, standards have been introduced which limit the power of radio signals at the surface of the earth originating in transmitters located in satellites. The distances between the stations of both communications systems are quite large. Ground stations for satellite communication are located so that they are shielded from radiation from radio stations of other radio networks by hills or mountains. Antennas with a sharp directional diagram are used, in which the lateral radiation in the direction of stations belonging to other systems and the reception of extraneous radiations from the side are insignificant. In planning radio relay links, the stations are chosen so that the radiation from their transmitters will not be able to propagate in the direction of a stationary orbit on which communications satellites may be located.

Television and radio broadcasting stations operate on fixed wavelengths which are chosen for this purpose in accordance with international agreement. Therefore, the mass produced radio and television receivers produced in many countries are designed to work at these wavelengths. It is only at these wavelengths that generally available systems of satellite broadcasting can be employed. This limitation is done away with by using distributive satellites

1 GHz (Gigahertz) = 1,000 MHz = 10^9 Hz.

as well as adaptable and collective systems, since in the latter cases the frequency (length of radio waves) of the transmitter located in the satellite can differ from the frequency to which the subscribers' receivers are tuned. This is explained by the fact that the frequency of the signal received from the satellites can be changed to any other frequency in a special ground-based /20
apparatus which will correspond to the working range of the receivers located in the home.

The distributive system is a typical example of satellite radio communication for which international agreements have set aside a sufficient number of working wavelengths to be used jointly with ground-based systems of radio communication.

In the first stage of study and development of satellite communications (1958-1963) the setting aside of wavelengths for this type of communication was an important problem. Its solution depended on whether or not new systems could function without generating noise in already existing, highly developed radio systems and without themselves being subject to noise from such sources. At the end of 1963 an extraordinary Administrative Conference on Radio Communication (EACR) was held in Geneva, attended by representatives of the member nations of the International Telecommunication Union, to which the Soviet Union belongs. The decisions of the EACR established the ranges of radio waves for radio systems to be used in space and also established technical standards for satellite communication systems. This enabled satellite systems to operate on common radio frequencies with existing ground telecommunications systems.

The following frequency ranges are set aside for satellite communication: for the "earth-satellite" radio channel, 4.4 to 4.7 GHz, 5.725 to 6.425 GHz and 7.9 to 8.4 GHz; for the "satellite-earth" channel, 3.4 to 4.2 GHz and 7.25 to 7.75 GHz.

Selection of the technical characteristics of a ground network of television and radio broadcasting depends to a large extent on considerations of maximum simplicity and low price of subscriber receivers by increasing the power and complexity of the transmitting stations. This sort of approach is necessary since existence of a very large number of receivers (hundreds of thousands or millions) would mean that increasing their number would be reflected in the total cost of the system to a greater extent than increasing the cost of the transmitter.

In the case of satellite broadcasting the requirement for simplicity of subscriber receivers remains in effect, of course. However, significant increase in the power of the transmitter located in the satellite poses very great difficulties. For this reason, selection of the principal parameters for systems of satellite broadcasting is much more complicated and requires simultaneous consideration both of the ground receiving network and the equipment aboard the satellite.

The following radio frequency ranges are set aside for television broadcasting in Europe[3]: I--48.5 to 66 MHz; II--76 to 100 MHz; III--174 to 230 MHz; /21
IV--470 to 622 MHz; V--622 to 958 MHz; VI--11.2 to 11.7 GHz. It is ranges I, II and III (meter wave) which are used most. Ranges IV and V (decimeter waves) have begun to be used recently in some countries.

If a question had arisen regarding the construction of a generally available system of direct satellite broadcasting, transmissions from a satellite would have to be made on wavelengths in the ranges given above, since the broadcast could not be picked up on existing receivers if they were on other wavelengths. Ranges (or bands) IV and V have been used to the greatest extent, since noise in the radio receiver caused by cosmic and terrestrial sources is less on the decimeter wavelengths than it is on meter waves. In addition, the transmitting and receiving antennas in this band can have comparatively sharp directionality with small dimensions. (Waves set aside for satellite broadcasting would have to be excluded from use by ground communications networks over the entire territory covered by the radiation from the satellite.)

In the case of an adaptable or collective system of satellite broadcasting, the wavelength of the transmitter aboard the satellite can be selected anywhere within the limits of the bands set aside for satellite communications.

[3]The frequency distribution differs somewhat in other parts of the world.

It is necessary however to observe the standards set up by the EACR which insure that the same wavelength can be used by ground systems for other purposes. These standards mainly limit the power of the signal radiated by the transmitter aboard the satellite to the earth. Since the maximum admissible power is small, this signal received from the satellite on earth is too weak for it to be able to be picked up directly on conventional receivers. This problem can be solved with the aid of attachments which are used in conjunction with adaptable systems and especially collective systems.

Power of Transmitters Aboard Satellites

The limited possibilities for mounting radio equipment aboard a satellite, the impossibility of servicing it, the extremely high demands made on reliability and reserves, the need to protect it against disturbing effects of radiation--all of these have required special technical solutions in planning satellite communication systems. These features have necessitated the construction of particularly compact, light and relatively simple apparatus aboard satellites, using transmitters with low power and a slightly directional antenna. The required technical indices of the system on the whole have /22
been achieved by making the equipment at the ground station more complicated. The latter has been equipped with a high powered transmitter, complicated supersensitive receiver, large highly directional antenna with a system of precise tracking of the satellite; the latter is equipped with powerful electrical devices for turning it, automatic regulators, a programming and computing system, etc. The most suitable wavelengths have been selected for transmitting television broadcast programs from the satellite to the earth. The solution of this very difficult problem has required the efforts of large scientific and industrial organizations and has incurred considerable material expense.

In view of the above, one can imagine the extreme difficulty of solving the problem of a generally available system of direct satellite broadcasting: in this system, it will be necessary to do away with complex ground receiving equipment and concentrate on the simplest mass receivers; it is also necessary to avoid selection of the optimum (most favorable) wavelengths and to use the frequencies employed in conventional television broadcasting. In order to solve a problem of this type it would be necessary to complicate the equipment aboard the satellite mainly to increase the directionality of the satellite antenna and increase the accuracy of its aiming at the earth, as well as to increase the power of the satellite transmitter many times.

Reports of the International Advisory Committee for Radio Communications contain designs for several versions of satellite systems used for direct broadcasting. One of them suggests generally available broadcasting through a stationary passive satellite 100 m in diameter. In order to receive from such a satellite a signal that could be picked up by home receivers over a territory equal to the size of France, a 30,000 kW transmitter would have to be built on earth and would require a highly directional transmitting antenna several kilometers in diameter. However, television transmitters of such power and antennas of such size are practically unrealistic. This supports the opinion expressed earlier regarding the impracticality of passive satellites for television broadcasting systems.

Three versions were suggested for a system using an active satellite, employing different wavelengths and able to ensure television broadcasting from a stationary orbit to approximately 30% of the surface of the earth. For example, for a broadcast that would be generally available on the meter wave frequencies most often employed in all countries, an antenna in the form of a parabolic mirror 18 m in diameter would have to be mounted on the satellite and aimed toward the earth. A source of electrical energy capable of delivering a power of more than 40 kW would be required to power the transmitter /23 aboard the satellite; this is considerably higher than the maximum power currently available. The construction of satellites of this kind and their launching would require the solution of extremely complex technical problems as well as immense expenditures.

Distributive and collective systems of satellite broadcasting are of the greatest practical importance at the present time. In this case, no special requirements are placed on the power of the transmitter aboard the satellite although it is necessary to keep in mind that the larger the latter is made, the simpler and more cheaply the ground stations or collective installations can be. A considerable increase in power relative to the level attained in the first designs of communications satellites is desirable for a broad development of distributive systems and necessary for building a collective system.

Ground Stations for Satellite Communications

In recent years, ground stations for satellite communications have been built in many countries and some nations (USA, Australia, England, West Germany, etc.) have several stations.

There is a large network of ground stations in the USSR. We have more than 25 receiving stations (Figure 13) in the "Orbita" system: Murmansk, Arkhangel'sk, Syktyvkar, Vorkuta, Noril'sk, Magadan, Petropavlovsk-Kamchatka, Komsomol'sk-on-Amur, Bratsk, Ashkhabad, Surgut and other locations. In case of necessity these stations can be converted to receiving-transmitting stations. Many more stations are being added to this network.

An important part of the equipment at each ground stations in a satellite communication network is the large antenna with parabolic reflector (see Figures 13 and 14). It is automatically aimed precisely at the satellite with the aid of a signal from the radio beacon mounted aboard the satellite. The reflector diameter is between 12 and 30 m and may be even larger. In order to protect the antenna from the effects of precipitation and wind, it is sometimes housed beneath a thin spherical dome which is transparent to radio transmission (radome).

The ground station transmitters have a power from 2 to 10 kW.

The receiver at a ground station usually consists of two units. The first is mounted in a special housing directly on the moveable antenna. This insures the minimal length of the waveguide which connects the antenna to the /24
input of the receiver, thus making it possible to avoid energy losses in the weak signal picked up from the satellite. In order to reduce the natural noise from the receiver, which disturbs the reception of weak signals, the

input stage of this section usually consists of a special low-noise amplifier (molecular or parametric) cooled by liquid nitrogen or liquid helium.

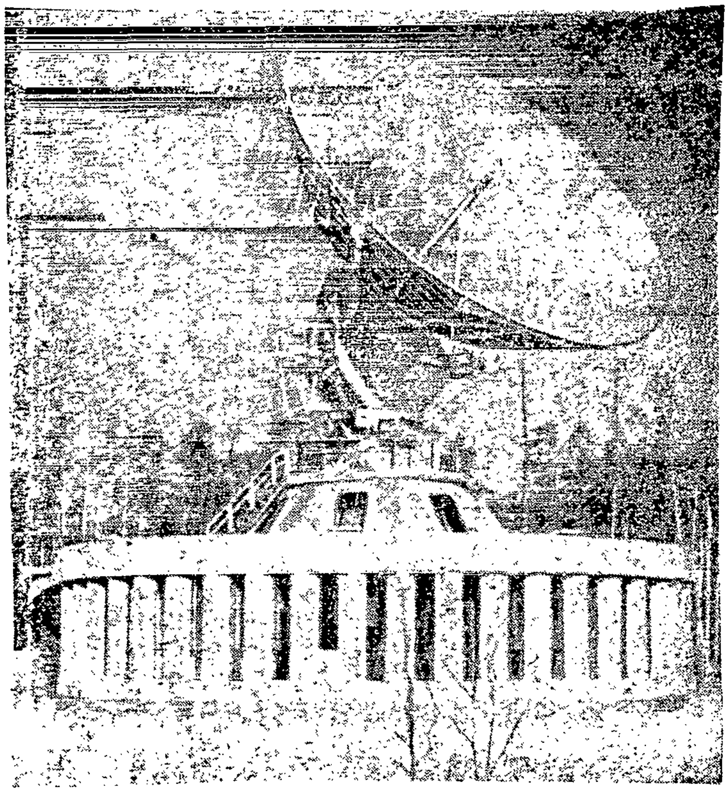

Figure 13.

After preliminary amplification and frequency transformation, the signal passes from the first unit through a cable to the second and final receiver unit mounted in a fixed location in the station.

Design of Communication Satellites

The design of satellites, methods of launching and controlling them, etc. is a complicated field of technology which cannot be discussed in detail within the scope of this booklet. We will limit ourselves to only a few of the problems involved in the operation of a satellite in the communications system which has been suggested.

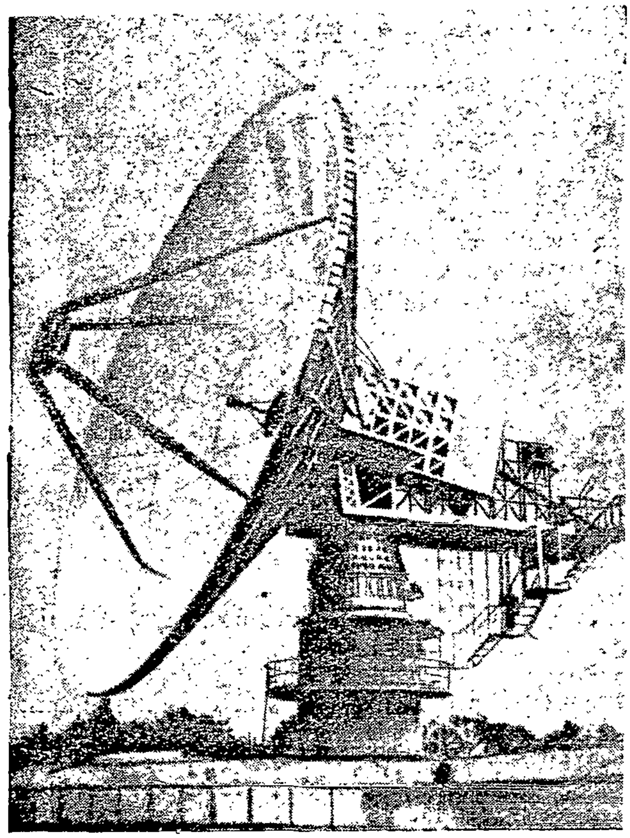

Figure 14.

As we have already pointed out, the principal difficulty in establishing direct satellite broadcasting is the need to have a sufficiently powerful transmitter aboard the satellite to generate a powerful signal in the antennas of the ground receivers. From this standpoint, it is interesting to compare the two principal possibilities for operation of the satellite: /26

1) Radiation of radio waves from the satellite takes place in all directions. The disadvantage of this variety for broadcasting is obvious: only a small portion of the radiated energy reaches the earth. However, the radio waves will reach the earth at any position of the satellite, even if the latter is "tumbling"; the latter is unavoidable if the satellite has no special devices for regulating its position.

2) The radiation of radio waves is directed in only one direction, toward the earth. The advantage of this case consists in the increase in the

energy of the signal to the earth without increasing the power of the transmitter aboard the satellite. For example, the earth is visible from a stationary orbit at an angle of approximately 20°. Concentration of all radiation in this angle would be equivalent to increasing the power of the transmitter 300 times in comparison to the previous case. With a sharper directional diagram for the antenna, insuring a concentration of the radiation in more populated areas, the equivalent increase in power would be still greater.

It is difficult to mount a very powerful transmitter aboard the satellite for the following reasons[4]:

--the large size and weight (very large and heavy satellite would be required, whose launching would be very difficult and expensive);

--powerful sources of electrical energy would be required, such as very large solar batteries, which would also increase the size and weight of the satellite;

--the operation of a powerful transmitter is accompanied by considerable liberation of heat, which must be removed and dissipated into surrounding space. This also leads to a complication of the design and an increase in the size and weight, so that the second of these satellite types is preferable. In this case, however, the antenna must always "look" at the earth, which requires regulation of its position or the mounting of the entire satellite with the antenna attached.

The control of the position of an object located on earth does not pose particular difficulties: "holding on to the earth", an object can turn in any direction. There is no shortage of electrical energy to power its motors. /27
Controlling the position of an object in space is much more difficult: there are no supports to "hold on to", which would allow the satellite to turn or arrest its motion.

[4]In view of the limitations imposed by the EACR, increasing the power would first of all require a corresponding international agreement.

The principal means of affecting the spatial position of a spacecraft or satellite were pointed out by K. E. Tsiolkovskiy. One of these is the use of small rocket motors, operating for example from tanks of compressed gas. Another method is the spinning or braking of massive flywheels mounted aboard the satellite: the mechanical action on the flywheel causes an opposite effect on the satellite. In this case, electric motors can be used.

Three independent problems can be mentioned in conjunction with controlling a communications satellite:

1) maintenance of the desired orbit. The influence of the magnetic and gravitational fields of the earth, solar radiation and other causes produce a gradual change in the orbit. To compensate for them, correcting jet motors are switched on from time to time. The factors causing deviation are weak in the case of a flight far beyond the limits of the dense layers of the atmosphere, so that frequent corrections are not required. A circular equatorial orbit is the most stable;

2) stabilization of the satellite, i.e., ensuring relative stability of its position relative to the earth, stopping "tumbling";

3) orientation of the satellite and antenna, i.e., ensuring its fixed position relative to the earth at a point where the radiation from the antenna is directed in the required geographical area.

Figure 15 shows an elliptical and a circular orbit. In a stationary circular orbit satellite C_1 is fixed relative to the territory it serves A; this simplifies the problem of orientation. In order for the antenna of satellite C_2, in an elliptical orbit, to be directed toward territory A, continuous /28
operation of the orientation system is required.

As in any navigational system a satellite orientation system requires devices which determine directions in space. On ships, instruments of this kind include magnetic and gyroscopic compasses, radio compasses, sextants, etc. The use of a magnetic compass on a satellite with a high orbit is practically impossible, since the magnetic field of the earth is too weak at great heights. Instruments which use visual orientation, especially relative to the sun and earth, are more convenient and reliable. The desired directions are determined by precise gyroscopic instruments connected to the automatic orientation system. Modern instrument technology provides adequate means for solving problems of this kind.

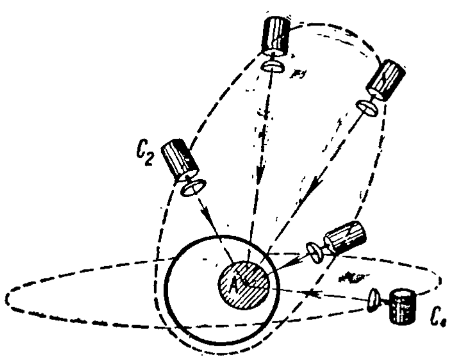

Figure 15.

The first Soviet communications satellite was placed in a high elliptical orbit ("Molniya-1", Figures 16 and 17); it was launched on April 23, 1965. After correction of the orbit, the height of the satellite at apogee was approximately 40,000 km, and its period of revolution was 12 hours, i.e., the satellite made two revolutions around the earth every 24 hours. The satellite passed over the territory of the USSR in one these revolutions and over North America on the other. A jet motor was mounted aboard the satellite for correcting the orbit. Many other satellites of this type have been launched in subsequent years; they have proved themselves completely and now provide regular transmission of television programs. /29

The "Molniya-1" satellite has a cylindrical body with conical ends (see Figure 16). Six panels with solar batteries are mounted on the outside of the body. These unfold like the petals of a giant daisy after the satellite separates from the rocket. Two parabolic antennas are mounted on hinged arms attached to the body, and are also folded prior to separation of the satellite like the solar batteries. The satellite is oriented toward the sun in flight in order to obtain the maximum energy from the solar batteries. One antenna is aimed by a tracking mechanism toward the earth while the other is a standby. The power of the radio transmitter located aboard the satellite is 40 watts.

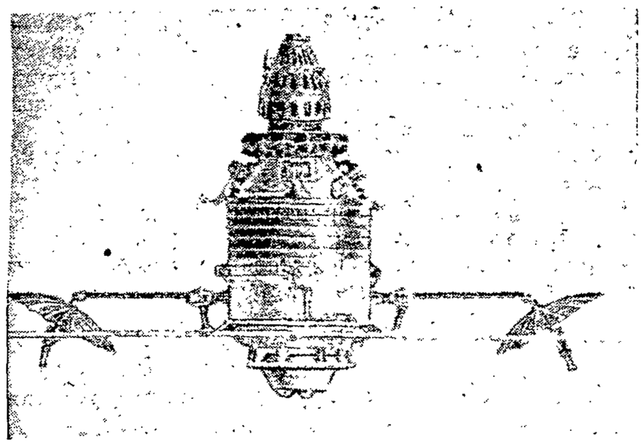

Figure 16.

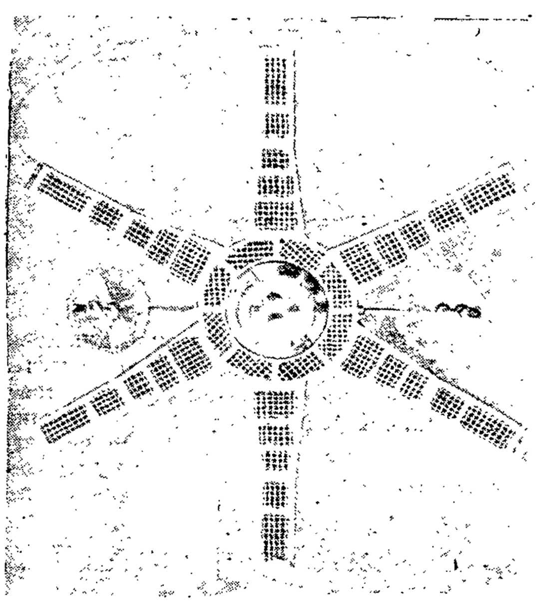

Figure 17.

The successful launching of an experimental version of a stationary communications satellite was first accomplished by the United States in 1963. Several similar satellites have been launched since then, providing regular trans-oceanic communication. The procedure for launching them is comparatively complex. It consists of three stages. /30 Several minutes after launching, which takes place at point A (Figure 18), separation of the second rocket stage takes place at point 1 and correction of the spatial position of the system is performed on command from earth prior to ignition of the third stage. In the second phase, approximately half an hour following launch (on passage through the plane of the equator), the third rocket stage is ignited, placing the satellite in transitional elliptical orbit 2-2 (see Figure 18), whose plane is inclined to the plane of the equator. Turning on the jet motor in the system for orbital correction then matches it with the equatorial plane. The axis of the satellite is first oriented so that the thrust of the engine changes the orbit in the required direction. In the final phase, the "apogee" jet engine is cut in and places the satellite in a circular equatorial orbit 3-3. Then the control system aboard the satellite keeps it in the required stationary position.

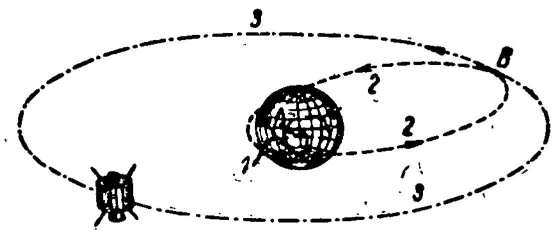

Figure 18.

Figure 19 shows an external view of one of the first stationary satellites, the American "Early Bird" satellite. It has /31
a cylindrical surface covered with solar batteries. A satellite of this type can either transmit 240 telephone conversations, simultaneously transmit two television programs, or carry one television program and about 100 telephone conversations.

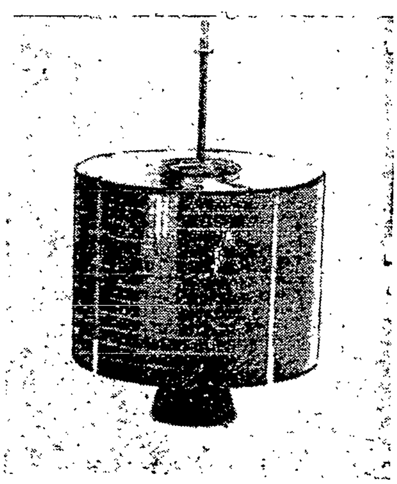

Figure 19.

An important feature of this satellite and the other stationary satellites launched thus far is the use of stabilization by rotation. When it is in its normal position in orbit, the axis of the satellite is parallel to the earth's axis. The satellite is set to rotating around its axis by means of a small jet motor. As a result, due to the gyroscopic effect, the axis of the satellite keeps its position fixed in space (like the axis of a gyroscope). One positive aspect of such a method of stabilization is that the role of the gyroscope is played by the satellite itself with all the equipment located aboard it. However, if special gyroscopes were provided for this purpose and were mounted in the satellite, the equipment required for them would take up considerable portion of the volume and weight of the satellite. Another important feature is that since the satellite is rotating in space, there is no friction, i.e., the rotation and therefore the stabilization are maintained without additional energy expenditure.

If the axis of rotation of the satellite deviates from that initially set under the influence of some factor or other, the correct position is restored by a correction system oriented to the sun or earth. The active unit in the correction system is a small jet motor which provides a tilting force in any direction to the axis of rotation of the satellite. If the force is applied for example in the plane YOZ (Figure 20), i.e., directed around axis X, the direction of the axis of rotation of the satellite will turn in the perpendicular plane around the axis Z. As soon as the action of the force has ceased, the axis of the satellite will cease to turn and it will retain its new position in a stable manner. /32

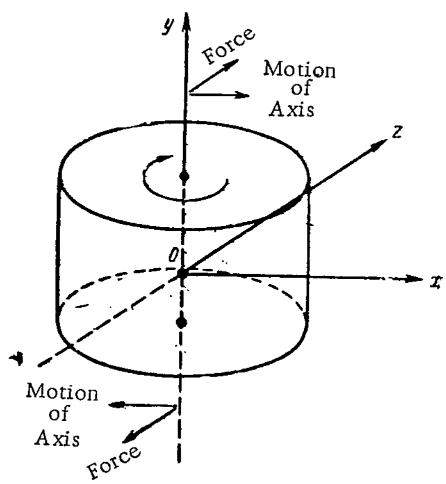

Figure 20.

In addition to the considerable advantages of stabilization of a stationary satellite by means of its rotation, the use of this method entails complications in the orientation of the antenna. When the satellite rotates, the antenna mounted on it rotates along with it and therefore, (if no special measures are provided) it cannot "look" continually in a required direction, i.e., at the earth.

The problem of orientation of the antenna was solved only partially in the first stationary satellites. An antenna was used which radiated radio waves in a plane perpendicular to the axis of rotation of the satellite in all directions (Figure 21), but the radiation was concentrated in the angle α in the longitudinal plane. Of course, a great deal of power is also lost in this arrangement, but the flow of radiation to earth is much more intense than would be the case if the radiation were isotropic, i.e., the same in all directions.

The design of stationary satellites calls for making sure that the radiation of the radio waves will occur only in the direction of the earth. It is

obvious that this cannot be assured if the antenna aboard the satellite radiates in a direction which is fixed relative to the satellite, since in this case the antenna would rotate along with the satellite and the direction of radiation would change accordingly. When the satellite is stabilized by rotation, there is one way to solve this problem: with the satellite rotating at any angle, the direction of radiation must rotate to the same angle but in the opposite direction so that it retains its orientation with respect to the earth. This problem was partially solved by electronic means (without mechanical rotation of the antenna) in the ATS-1 satellite (Figure 22) with a 40 watt transmitter, which was launched by the United States in December 1966. /33
The antenna consists of 16 rods forming a cylinder. A special device (phase shifter) varied the phase of the oscillation fed to the rods in a certain order. As a result the direction of the radio wave radiation will change and can be aimed in the required direction. The satellite has a device which measures the rotational parameters of the satellite relative to the earth and controls the antenna by an electronic phase shifter so that the reverse rotation of radiation exactly matches the rotation of the satellite in the opposite direction.

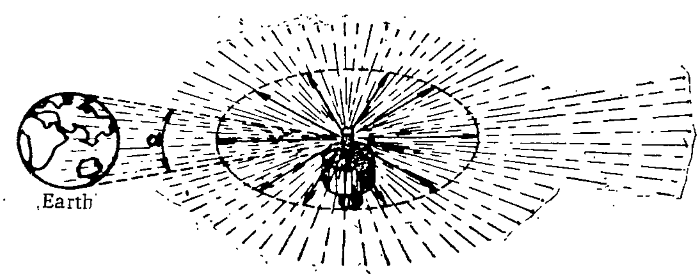

Figure 21.

In view of the difficulty of designing a satellite-mounted antenna with sharp directionality on the principle described, designs using a mechanical reverse-rotating antenna have been developed. The idea of such a system is explained in Figure 23: the antenna and satellite rotate as shown by the arrows in the figure. When they are rotating at the same speed, the antenna (and consequently the direction of radiation) actually remain fixed in space. /34
The potential possibilities of systems with mechanical rotation of the antenna are limited. In order to obtain a high degree of

directionality of the radiation, the antenna dimensions must be large and therefore their mass will also be great.

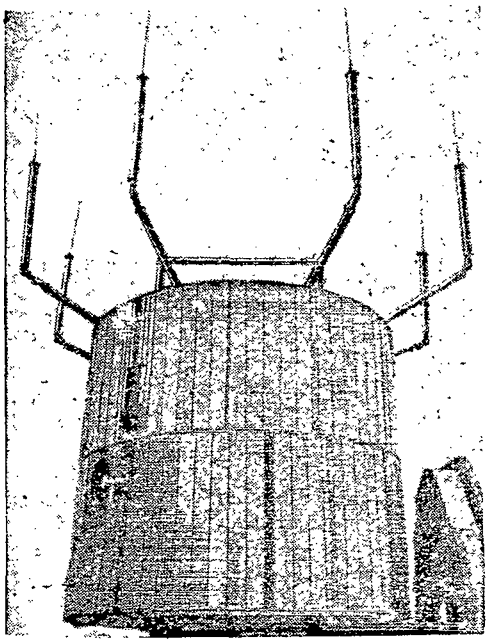

Figure 22.

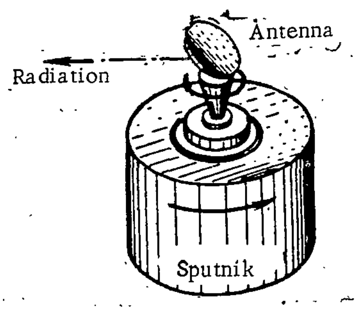

Figure 23.

Since a large portion of the mass of the system does not actually participate in the rotation in the case of a large antenna, this would reduce the effectiveness of the stabilization. In addition, systems of this type require continuous expenditure of energy to overcome friction in the bearings of the rotating parts. Therefore the designers of communications satellites study other possibilities of stabilization which are made possible by using large antennas. Considerable interest has been attracted by stabilization systems based on the use of changes in the strength of the gravitational field as a function of distance from earth, which under certain conditions will lead to the appearance of mechanical moments that keep the axis of the satellite directed toward the earth (Figure 24). This effect in particular is responsible for the fact that the moon always keeps one side turned toward the earth, i.e., in revolving around the earth it simultaneously rotates around its own axis through 360°. It is conceivable that this principle could be used to make a large stationary satellite with a large antenna.

The considerations given above relate to transmitting antennas located aboard satellites. The requirements for a receiving antenna on a satellite /35 are less stringent since the ground transmitting station can have a transmitter with greater power and a highly directional antenna, i.e., it can project a signal to the location of the satellite which can be picked up by a small simple antenna.

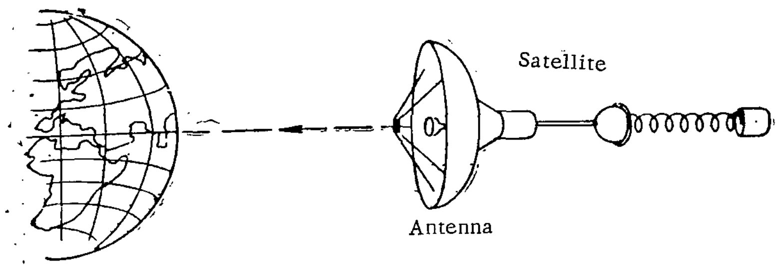

Figure 24.

It should be pointed out that the dimensions and weight of a satellite of the "Molniya-1" type on an elliptical orbit with a height at apogee equal to the radius of the orbit of a stationary satellite and consequently the power of the radio equipment on board can be significantly greater than in the case of a satellite in a stationary orbit for the following reasons. From the description given above of the process of insertion of a satellite into a stationary orbit, it is clear that the transition from the elliptical orbit to the circular one requires consumption of energy by a rather powerful jet motor with a required fuel reserve. If the transition to the circular equatorial orbit is omitted, the weight and volume of this motor and its fuel supply can be replaced by additional or more powerful radio equipment. The difference in the payload of satellites launched into the same height reaches a factor of 2 to 3.

<u>Sources of Electrical Energy Aboard Satellites</u>

In solving the energy problems related to the design of satellites for long term service, two approaches are possible:

--storing aboard the satellite the supply of material which can be consumed gradually to produce electrical energy;

--use of the flux of solar energy by means of converters located aboard the satellite.

The second approach is more advantageous in principle, since the supply of material that can be stored aboard the satellite is finite while the amount of solar energy is practically infinite. Therefore, a converter which does not lose its properties in the course of operation can insure a long service life for the system. It is possible that under actual conditions the optimum solution depends on the results of development of both methods of obtaining energy achieved by the time of their comparison. Chemical sources of electricity are suitable for low powers and comparatively short operating times. Nuclear sources, however, have a much greater service life in comparison with chemical ones.

In the majority of satellites and spacecraft which have been launched to date, solar batteries have been used as a source of electricity. The flux of /36 solar energy beyond the limits of the earth's atmosphere is about 1.4 kW/m^2. the maximum efficiency of silicon solar batteries is about 20% (at present, solar batteries with an efficiency of 12-14% are being used). When tracking systems are used to orient automatically the surfaces of the batteries with respect to the sun as is done on the "Molniya-1" satellite, their specific area per unit power can reach approximately 10 m^2/kW. If it is possible that the satellite will be shaded, continuity of the energy supply is insured by combining the solar batteries with a storage battery. One disadvantage of solar batteries is the fact that they are damaged by the action of cosmic radiation of solar or other origin. Transparent screens made of quartz or sapphire are used to protect the solar elements. Elements which have an increased resistance to radiation have been developed recently. In this case, the weight of the screens can be reduced considerably. Considerable interest has also been aroused by thin-film photobatteries, for example, those made of cadmium telluride or cadmium sulfide, which have good resistance to radiation.

In order to produce significant power, a solar battery must have a large area; this complicates the design and launching of the satellite. Powerful nuclear energy sources are more compact; they include isotope batteries and devices employing reactors. The advantages of atomic installations is the need to shield the electronic equipment aboard the satellite from the disturbing effect of the radiation produced by the built-in energy source. According to foreign data, the weight characteristic of nuclear energy sources is approximately 1 watt/kg, taking into consideration the means for shielding against radiation. Studies and designs in this field are still far from complete and we can expect in the future a considerable improvement in the effectiveness of the electrical power sources installed aboard satellites.

Possibilities of Launching Satellites for Television Broadcasting

It follows from the above that one of the principal problems in direct satellite broadcasting is the launching of the heavy satellite with a sufficiently powerful radio transmitter, effective antenna and energy source with sufficient power. Existing satellite communications systems, whose built-in transmitters have powers on the order of tens of watts, only allow the installation of a relay system for television broadcasting with complex and expen- /37
sive ground receiving stations. In order to realize a generally available system of satellite television broadcasting, the power of the transmitter must be increased by thousands of times; this would require a satellite weighing tens of tons.

Depending on the increase in the satellite payload which is achieved when the latter has been placed in its selected orbit, the problem of the practicality of a given intermediate system can be solved, especially in the case of the most practical type, the collective and distributive, with simplification of the ground equipment. The weight of the "Proton" research satellites, launched into an orbit with an apogee measuring hundreds of km, approaches two-tenths of a ton. Spacecraft weighing less have been launched into higher orbits. In particular, the comparatively large American stationary communication satellite ATS-1 mentioned earlier has a weight of approximately 360 kg.

The latest achievements of spacecraft technology will undoubtedly make it possible to launch heavy satellites into a stationary orbit. The weight of a satellite in an elliptical orbit of the type used by the Soviet "Molniya-1" satellites would be correspondingly greater.

The First Satellite Television System in the World

At the present time, more than 25 ground stations in the "Orbita" system are operating in the Soviet Union. Each of them transmits television programs received from a satellite to a local television broadcasting center, which sends them out over the region which it serves. On the average, each "Orbita" ground station allows the programs from the central television studios to be received over a territory with a population on the order of a million people; more than 25 million citizens of our country have been enabled to see and hear television programs transmitted from Moscow. They are present in Red Square during the holiday parades and demonstrations; they hear important political and cultural reports directly. As a result, the idea of "the Provinces", "the periphery", etc. as well as a sense of remoteness from the center of life in our country is disappearing. It is true, however, that all the stations in the "Orbita" system are actually very far from Moscow. Television broadcasts from Moscow are picked up in the cities and small villages, many of which until now were linked to the center only by telephone, telegraph /38
or radio; they are picked up at places which are separated from the central regions by many hundreds of kilometers of desert, mountains, taiga and tundra, and which have still not been reached by railroads or highways.

Twenty-five million citizens! And this number is growing, so that the "Orbita" system will continue to expand.

It would be possible to accomplish this without using a satellite, by means of radio relay and cable lines, but this would require the construction of no less than 50,000 km of such line and thousands of intermediate receiving-amplifying points. This would require an enormous expenditure of resources and, what is most important, would require a long period of time. Thanks to the satellites, the problem was solved very rapidly and has considerable possibilities for further equally rapid development of the distribution network. The programs of the Central Television Studios can be picked up at any point served by a "Orbita" station.

Having the exclusive ability to "step over" any obstacles, over mountain ranges and oceans, satellite communication systems will open up the broadest possibilities for constructing international television broadcasting on a global scale, i.e., broadcasts that would take in all parts of the world.

In August 1968 at Vienna, a United Nations Conference on the Investigation and Use of Space for Peaceful Purposes was held. A plan for agreeing on the organization of an international communications system using satellites was presented at this conference; it was presented to the United Nations by Bulgaria, Hungary, Cuba, Mongolia, Poland, Romania, the USSR and Czechoslovakia. It anticipates cooperation of these countries and coordination of their work in building and using an international system which would be available to any country to join which wanted to do so and would accept the organizational principles. An important feature of the plan's system is its extremely democratic nature, being of equal importance for every participating nation regardless of whether it is large or small, whether its material contribution to the construction of the system is considerable or slight. To direct the operation of the system, a council has been formed which includes one representative of each member nation of the organization. Each country has one vote in the council.

The international satellite communication system based on equal democratic principles, is the first of its kind. At the present time, countries which are interested in gaining access to communications satellites must become members of the commercial consortium "Intelsat", whose regulations state that more than 50% of the shares belong to the United States. Accordingly, the United States has a monopolistic right to decide all important questions in this organization. The control of the consortium is actually in the hands /39
of the American "Comsat" Corporation.

In addition to the international systems, some countries with large territories, such as the United States and Canada are planning to build distributive satellite systems for purposes of television broadcasting which are similar in all respects to the Soviet "Orbita" system.

Some Conditions for Realization of Satellite Broadcasting Systems

As we have already pointed out earlier, satellites for practical communications and broadcasting systems can be stationary or launched into a considerably elongated elliptical orbit. From the standpoint of the requirements on the broadcasting system, each variety has the following advantages and features.

Satellite in a Stationary Orbit:

--unlimited duration of continuous broadcasting via a single satellite;

--a minimum number of satellites to achieve a global system;

--comparatively simple design for the ground highly directional receiving antenna which need not rotate to follow the satellite as it moves in its orbit; it can be fixed. Continuous communication is achieved by means of a single antenna. In the case of a moving satellite two antennas are required in principle; one tracks the satellite from which the transmission is coming and the second picks up the second satellite which arrives to replace the first;

--the satellites are located beyond the limits of the belt of cosmic radiation which has a disturbing effect on the radio apparatus on board;

--the strength of the signal from the satellite to the earth is constant;

--there is no variation in the frequency of the radio signal caused by motion of the satellite (Doppler effect) and capable of disturbing the transmitted images;

--a reduction of the probability of mutual interference between the satellite and ground communications stations due to constancy of the direction of arrival of the signals from the satellite, making it possible to use ground antennas with fixed direction and to take measures to protect the satellite from noise originating in other ground systems as well as to protect ground systems from noise originating in the ground stations of a communications /40
satellite network.

Satellite in an Elliptical Orbit:

--it makes it possible to have reliable reception at high latitudes where the stationary satellite does not ensure favorable conditions for reception due to the small angle of incidence of the wave relative to the horizon;

--there are simpler and more economical means for launching the satellite or at a height at apogee equal to the radius of a stationary orbit, the possibility of placing a heavier satellite in orbit;

--the possibility of using one satellite to broadcast over territories located in the Western and Eastern Hemispheres. To do this at least two stationary satellites would be required.

In constructing global systems of satellite television broadcasting it will be advantageous to have combined use of satellites in orbits of both types.

In the years to come, it will be technically feasible to build not only distributive but also collective broadcasting systems based on the use of either of the two types of orbit, with consideration of the advantages of one or the other for the given geographic conditions. The generally available type of system will become technically feasible still later. However, the construction of a satellite with the required technical characteristics will still be a long way from doing away with the problems of satellite broadcasting. There are many other serious and contradictory problems on which not only the technical solutions but the actual feasibility of the system depends.

One such problem is the frequency band. For a long time it was felt that the meter, decimeter and centimeter waves could be used for communication and broadcasting only over a small zone with a radius of 40-60 km. This was considered a shortcoming of these bands, but at the same time it was an actual advantage since it made it possible to use the same waves many times in various places on the globe with a considerable directionality of the radiation, even within the limits of a single neighborhood, if the transmissions were made in different directions. In addition, the width of the frequency bands in these ranges is hundreds of times greater than the "old" decameter band which is nearly completely occupied by operating radio stations that have already begun to interfere considerably with one another. The meter, decimeter and centimeter waves offer nearly unlimited possibilities for further /41
development of radio broadcasting systems and radio relay networks. This position changed somewhat when radio communication lines developed using meter and decimeter waves with ionosopheric and tropospheric scattering, making it possible to transmit directly without intermediate relay stations over

distances up to 2,000 km. The development of this new type of communications via satellites on the one hand offered considerable hope for successful solution of some very important problems, while on the other hand it has already completely destroyed the illusions of the unlimited capacity of these bands and has created a demand that will soon lead to the same difficult situation which has already existed for a long time in the decameter wave.

A number of studies have already shown the advantages of frequencies on the order of 2 GHz for satellite television broadcasting. But this band is already widely used for fixed and mobile communication systems; the question of the possibility and conditions for combination of these systems with satellite broadcasting will require careful discussion. Other projects have recommended the use of bands at frequencies of about 650 and 800 MHz for direct radio broadcasting from satellites. However, conventional "ground" television broadcasting has already been planned for these bands and is undergoing practical development.

In designing a satellite television broadcasting system, it is necessary to take into account both the enormous effect of distance and the limited dimensions (and therefore, the power) of the satellite. This has forced designers to concentrate on a signal strength on the satellite which is close to the minimum admissible limit. At the same time, however, the signal strength of a ground broadcasting transmitter has such a value only at the limits of the zone it serves, and considerably exceeds the minimum level over most of this zone. This would mean that satellites broadcasting would be subject to considerable interference from ground stations broadcasting in the same vicinity if there were not a sufficient distance in the range between the bands in use in order to obtain the required tuning of the receiver.

Since satellite communications systems cover very large territories, the solution of the problem of the freeing "exclusive" frequency bands for their use is impossible without international agreement. The problem of the possibility of increasing the maximum admissible signal strength from satellites broadcasting to earth can also be solved only on an international basis. These problems belong to the area of so-called electromagnetic compatibility

of different radio-technical systems, whose study has already received considerable attention in many countries. The determination of the possibility of selecting a system of satellite broadcasting (distributive, collective, etc.) will depend in large measure on the solution of the problem of the condition of electromagnetic compatibility. It is possible that the selection of the system and the technical means for satellite broadcasting will depend in the final analysis on its purpose, the size of the territory to be served by /42
them, and especially on the development of other broadcasting systems. If we consider that the purpose of the satellite system has to do with acceptable expenditures by the majority of the population, we must reckon with the fact that the majority of the population in many countries is concentrated in the cities and other more or less significant populated areas. In other cases, however, the more pressing problem may be broadcasting to mutually isolated small populated areas which are economically unable to have a ground network for television broadcasting.

Of these two situations, the first is the more pressing at the present time; the problem of broadcasting for densely populated territories is especially important because significant numbers of the population are concentrated in them. Experience has shown that satisfactory image quality on receivers with "rabbit ears" antennas is achieved in no more than 30 to 40% of the cases, while the required quality can be achieved in 60 to 70% of the cases only by installation of a roof antenna. Often these antennas must be comparatively complex. For technical, economic and aesthetic reasons, the use of master antennas is the most advantageous way of solving the problem. Of the USSR, all newly built residences are equipped with master antenna systems. Similar measures are being taken in other countries.

The second approach is to use comparatively low power converters to supply a signal of sufficient strength to the "rabbit ears" antennas. The industry in the USSR is producing, for example, completely automatic television converters with a power of two watts which are used in Kirghizia and some other locations in the Soviet Union where there are obstacles to the construction of direct radio wave propagation.

There is no doubt that collective television receiving systems will see further wide development in the years to come; this approach makes it possible to have sufficiently good reception of television broadcasts in cities. The successful use of systems of collective television reception will make it possible to recommend them also for the organization of a satellite broadcasting system, with a comparison of the two possible systems being necessary in each case: master antennas and low power converters. The second may be advantageous for small populated areas with scattered low buildings.

The method of collective reception, depending on the need, makes it possible to realize the following advantages:

--to use a separate antenna for satellite transmission reception, having improved characteristics with low expenditure for each individual subscriber;

--to select for broadcasting the most suitable wavelength without worrying about the ability of the subscribers' receivers to pick up the signals on this wavelength; /43

--to supplement the collective amplifier by a converter which will transform the signal broadcast by the satellite to one in the range picked up by the subscribers' receivers.

It is quite likely that actual systems will be a combination of the two. The signal from the satellite will be able to be picked up on nearly all television broadcasting studios and at television relay points. The programs picked up through the satellite will be included in the regular schedule of broadcasts for the territories served by these television centers and relay stations. The possibility of organization of broadcasts of individual programs at certain points that could be picked up via the satellite is not excluded. However, in locations where the local television broadcasting has not yet been organized and television transmitters are lacking or are impractical due to the low population density, a system of collective reception may be organized.

The dimensions of the zones served by a satellite system may be very large so that an increase in the territory and therefore in the number of subscribers will correspond to an increase in the economic efficiency of the system. In the case of very large areas, however, specific difficulties arise. One of these is the considerable difference in local time at points in the territory which are separated by a considerable amount of longitude. This difficulty is overcome in the converter system, since the broadcasts from the satellite can be recorded on film and then broadcast at a time more suitable for the population. Another difficulty is the increase in the number of languages of the population of the zone being served. Indonesia can serve as a characteristic example. This country is located on 6,044 inhabited islands on which about 100 million people live. It is obvious how important and how difficult it is to organize radio and television broadcasting there; but if we are talking about direct satellite broadcasting, we must keep in mind first of all that more than 100 nationalities, peoples and tribes live there, speaking in different languages and dialects. Having a satellite system with tens or hundreds of individual programs in different languages is a complicated solution whose feasibility is still not clear.

Another solution is to broadcast according to a schedule, with certain time slots being set aside for transmission in each language; however, the effectiveness of the system for each nationality is severely limited in this case. The third approach is to supply the audio portion of a television broadcast in various languages simultaneously. For example, when the television studio in the capital of Azerbaydzhan is broadcasting in the Azerbaydzhani language, the program is picked up by Russian inhabitants at Baku but the audio portion of the program they see is transmitted in Russian. To accomplish this, it will be /44 possible to connect a special attachment to the telvision receiver which can be purchased in stores.

The organization of direct satellite broadcasting to large territories, in Europe, Africa and in the nations of the Far East comes up against the problem of the large number of languages. In this case the solution of the problem by means of a multichannel, multilingual audio portion of the television broadcast using subscriber-owned attachments to select the necessary language would be very complex. The only acceptable solution to this situation is to use the converter system. The converter television station could have an announcer--interpreter and convert the signal, replacing the audio component or adding a sound channel in the local language. The solution of the language problem is facilitated when serving a small territory, i.e., in local broadcasting, but in this case it is also possible to do away with the need for satellite and use ground facilities. This makes it possible to reserve the frequencies for satellite communication in those places where it is more difficult to do without satellites. In addition, the concentration of radiation from the satellite within the limits of a small territory leads to increased complexity and cost of the satellite since a more precise orientation of its antennas is required and the size and weight are increased considerably. Consequently, there is a simultaneous reduction in the number of individuals served (since the territory served is smaller) and there is an increase in the cost of the satellite as well as increased cost of launching it. As a result, there is a considerable increase in the cost of the satellite system per inhabitant, i.e., the economic effectiveness of this system is less.

Foreign literature contains predictions of the development of the use of satellites in communications systems. For example, it is asserted that while satellite communications is able to serve only the most economically developed nations in the 1960s, by the 1970s it will already be in use in small countries and individual large cities, and in the 1980s increasingly large groups of subscribers will be tied into this system. In reality, of course, a city system does not require a satellite and it would be much better to use ground facilities. At the same time, however, the tendency to increase the number of communication satellites does not take into account the limitations of the available frequencies. In addition, the construction of satellite--mounted antennas with considerable directionality that will allow radio communication between the satellite and a small group of subscribers without interfering with the zones of other small groups is a very difficult problem. The ideal solution from the standpoint of preventing mutual interference is the use of cable lines. But as soon as radio appeared, there also appeared a tendency /45
to transfer to it all the difficulties that arose as a result of the shortcomings or absence of wire and cable lines; in the final analysis, this led to a severe overloading of the radio frequencies and a reduction in the actual effectiveness of the radio communications system. Therefore, telecommunications

systems with free broadcasting of radio waves must be used primarily in those places where no other system can be employed.

There is still another important factor which complicates the selection of the technical solutions and has an influence on the potential realizability of satellite communication systems; it is the difference in national standards of broadcasting, especially as concerns television. The problem of standards, like the problem of languages, arises as soon as there is a plan for using the principal advantages of satellite systems for broadcasting purposes, namely, coverage of a large territory. This advantage can be achieved in the majority of cases in international systems, but difficulties arise due to the fact that different television standards are used in different countries. For example, the USSR and many European countries use a standard of 625 lines in a television picture, while the United States, Japan, Canada, Brazil and other countries use 525. The number of images transmitted per second is also different. There are other differences as well. A similar situation exists in regard to color television.

Reception of a broadcast using a standard which does not correspond to that for which the receiver is designed is possible if the standard is converted; this calls for complicated equipment. Equipping every receiver with a standard converter is not possible so that satellite broadcasting with standard conversion can be considered practical only in the converter and collective systems.

The establishment of international systems of satellite communication calls for the solution of organizational and technical problems involving the equal use of the satellite by participating countries. This problem corresponds to the so-called "multi-station access" in satellite communications systems for which an optimum technical solution is still being sought.

Summing up what we have said up till now, we can conclude that the most practical systems for satellite communication in the near future will be the collective and converter types, since they make the following possible:

--to exploit to the fullest extent the possibility of receiving radio and television programs broadcast by a satellite to subscribing receivers; the converter system also has the possibility of reception on portable transistorized receivers whose popularity is increasing steadily among the population;

--to achieve complete compatibility with the master antenna systems now existing in the cities and enjoying increasingly wide application; /46

--to use the optimum wavelength for space communications on the "satellite-earth" line, regardless of the wavelength on which the subscribers' receivers can receive programs;

--to match the standard of the transmitted broadcast to the standard used in the country receiving the broadcast;

--to match the schedule of international broadcasts in the converter system with the schedule of local and national broadcasting, also for the convenience of the consumers;

--to repeat important broadcasts by transcribing them and broadcasting them later at a more suitable hour;

--to use a number of radio signal converters and special devices on the "satellite-earth" line for the best transmission quality and the least noise interference;

--to locate the ground receiving stations in an area where the best reception conditions can be attained for a given country;

--to reduce the power, weight, size and to simplify the design of the satellite aboard the transmitter, as well as the devices for providing electrical power, thus leading to a general reduction in cost of the most expensive part of the system, the satellite, and also to an increase in its reliability;

--to reduce the interference caused in ground telecommunication systems by the radiation from the satellite, by reducing the power of the transmitter aboard the latter and using highly directional receiving antennas at the ground stations, highly sensitive receivers, etc.

The question arises of whether it is possible to work on developing an adaptable or special system of satellite broadcasting as well as a generally available system. The answer to this question must be an unconditional "Yes".

Our country contains enormous territories with harsh climates and difficult natural conditions. In order to give the individual living and working in these areas the maximum benefits of culture, to give them an effective and daily communication with the cultural centers of the nation, it is extremely important to provide them with an opportunity to receive the programs of the central television service. In this case, it is completely possible to use receivers which are specially designed for direct reception of television programs from a satellite. Consequently, the construction of satellites for direct television broadcasting is an extremely important problem and a considerable amount of work must be expended in this direction.

Satellite communication is already playing an important role in development of the television and radio broadcasting industry, and this role will increase considerably in the near future. Although they will not replace the network of ground radio stations, but will be a valuable supplement to it, they /47
will make possible a considerable increase in the international exchange of television programs and will speed up the spread of radio and television to areas where it is presently still difficult to organize transmission of programs by ground means. The use of satellites will increase simultaneously with an expansion of ground broadcasting facilities in all directions.

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